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Quality practices as a mediator of the relationship between Lean practices and production fitness

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Abstract

Purpose – The purpose of this research is to test a model that incorporates investments in quality and Lean practices and production fitness constructs, originating in the theory of swift even flow (SEF), to provide insights into successful implementation of manufacturing practices.

Design/methodology/approach – This research uses data from the Global Manufacturing Research Group fourth round survey and empirically tests the relationships between investments in Lean practices and improvements in production fitness, using a sample of 844 plants in 17 countries.

Findings – The results highlight that the implementation of Lean practices yields better results on production evenness, when the company has higher levels of investments in quality practices. Therefore, the implementation of quality practices is a prerequisite for achieving higher production fitness.

Originality/value – The findings are important to the development and testing of operations management theory, as it integrates two research streams, manufacturing practices and SEF research, to gain insights into the interplay of manufacturing practices and how it influences the production fitness. For practitioners, this research assesses how better-performing plants compete. It provides operations managers with a better understanding of production fitness and how manufacturing practices foster its development.

Keywords Performance, Lean practices, Quality practices, Swift even flow theory

Paper type Research paper

1. Introduction

The perceived gap between theory and practice in operations management has attracted the interest of both scholars and practitioners. In an attempt to bridge this gap, early empirical studies in the area of operations management focused on the impact of individual action programmes to improve productivity using empirical data (De Meyer and Ferdows, 1990; Brown, 1996; Voss and Blackmon, 1998). Since then, numerous large-scale studies on manufacturing practices and performance have been carried out across Europe and the USA (Brown and Bessant, 2003). Building on these early studies, the International Manufacturing Strategy Survey examined the alignment of improvement programmes with strategic priorities. Likewise the Global Manufacturing Research Group (GMRG) and the "High Performance Manufacturing" (HPM) undertook large-scale empirical surveys of manufacturing and supply chain practices across the globe (Hallgren and Olhager, 2009; Kristal *et al.*, 2010).

Subsequently, a number of empirical studies focused on the role of manufacturing practices and their effect on operational performance. MacDuffie (1995) used the term "bundles" to represent the combination of innovative human resource (HR) practices that influence the manufacturing performance. Schonberger (1986) described the elements of

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world-class manufacturing using sets of practices such as just-in-time (JIT), total quality management (TQM), employee involvement and total productive maintenance (TPM). These manufacturing practices represent multifaceted concepts, and several scholars have grouped them into sets of manufacturing practices. Christiansen *et al.* (2003) investigated the relationships between the implementation of bundles of manufacturing practices such as JIT, TQM, TPM and HR and operational performance. They argue that companies do not necessarily have to conduct an extensive implementation of all bundles of manufacturing practices to perform well on all the performance dimensions according to their manufacturing strategy. Similarly, Kristal *et al.* (2010) used HPM data to investigate the role of quality management practices in the development of mass customization capability.

The diversity of manufacturing practices such as agile, Lean and quality, for example, reflects that the relationship between manufacturing practices and operational performance may be complex and multi-faceted (Hofer *et al.*, 2012; Wiengarten *et al.*, 2013a). Mackelprang and Nair (2010) argued that the existence of fit and alignment effects between manufacturing practices (i.e. Lean and quality practices) could be an explanation for the contrasting results on the link between Lean practices and operational performance. These effects are apparent when certain manufacturing practices (such as quality practices) affect the relationship between other practices (such as Lean) and performance (Danese *et al.*, 2012; Khanchanapong *et al.*, 2014). However, very limited research exists of the study of Lean practices and how they interact with quality practices (Garza-Reyes *et al.*, 2015). Most of studies to date have addressed the impact that Lean practices have on performance, neglecting the possible interactions with other practices that companies have or are implementing. Thus, the purpose of this paper is to add to the existing body of knowledge on Lean manufacturing practices and performance by proposing an integrated framework that investigates the mediating effects between investments in Lean and quality practices and their impact on operational performance (conceptualized as production fitness), using the theory of swift even flow (SEF) (Schmenner, 2012) as the theoretical lens. Although previous studies investigated the Lean/quality practice effects on operational performance, there is little research on the mediational effects (Prajogo and Sohal, 2006). Operations management (OM) research requires more mediation and moderation studies, to better understand the mechanisms through which the manufacturing practices yield superior performance (Rungtusanatham *et al.*, 2014). Our study contributes to advancing the OM knowledge, by testing the internal fit between Lean and quality practices taking a mediation perspective. It is important to note that this is the first study that attempts to conceptualize and empirically test the theory of SEF. This is a major theoretical contribution to the SEF research calls (Devaraj *et al.*, 2013, Schmenner, 2012). This study addresses two research questions. First, to what extent the Lean and quality practices impact the factory fitness? Second, to what extent the quality practices mediate the relationship between Lean practices and factory fitness?

The remainder of the paper is organized as follows. The next section presents a literature review of production fitness, the impact of Lean and quality practices on performance and the relationships between these practices. The hypotheses are developed and the research method is addressed. Then the results are presented, and it concludes with a discussion of the theoretical and practical implications of the study.

2. Literature review

2.1 Production fitness

The term production fitness was coined by Ferdows and Thurnheer (2011) as the ability of a production system to reduce its waste and non-value-adding activities and expand its core capabilities. They argue that factories must improve the speed of material flow and reduce overall variability associated with quality, quantity or time to achieve production fitness. The concept provides a holistic view of the development of production capabilities (Bortolotti *et al.*, 2015b). Companies that focus on building production fitness can expand their more complex capabilities, enabling them to respond in a leaner and more agile way to the demands from the market. The theory of SEF holds that the performance for any production system "rises with the speed by which materials flow through the process, and it falls with increases in the variability associated with the flow" (Schmenner and Swink, 1998, p. 102). According to this theory, productivity is subject to the speed and variability of the process flow. The theory unifies five well-established laws of operations management: variability law (Conway *et al.*, 1988; Kannan and Palocsay, 1999), bottlenecks (Goldratt, 1990), scientific methods (Box, 1994), quality (Deming, 1988; Gryna and Juran, 2001) and factory focus (Pesch and Schroeder, 1996). The SEF theory illustrates the importance of two flow elements: swiftness and evenness. Swiftness refers to the speed of production flow and evenness represents the variability associated with that process. In this paper, we conceptualize production fitness as production swiftness and evenness, which we now review in more detail.

2.1.1 Production swiftness. According to the SEF theory, productivity increases in line with the speed at which materials flow through the process. The speed of a process is measured as the average output of that process (machine, workstation, line and plant) per unit of time, and it is known as throughput time or throughput rate (Spearman and Hopp, 2008). Schmenner (2004) used the throughput time as a measure of process swiftness. Similarly, Muthiah *et al.* (2008) argued that production is best represented in terms of process flow over time and highlights that lower throughput time is an important source of productivity gain. Several studies used the theory of SEF as theoretical lenses; however, very few included the swiftness as a specific construct (Table I).

Similarly, Kher and Fredendall (2004) provided partial support for the proposition that reducing process flow variance improves flow time and suggest further research into the conditions where the flow time is reduced and the effects on process performance. Likewise, Powell and Schmenner (2002) identified that the shorter the throughput time of materials, the higher the output per unit of production labour input. However, throughput reduction or acceleration of a production flow requires more oversight and supervision of the process, and it can increase the unevenness of the flow, i.e. product defects, machine breakdowns and operator's injuries. Other studies have highlighted the effect of simplified material flow on supply chain integration and the process speed (Childerhouse and Towill, 2003) and the effect of bottlenecks, quality problems and operational failures. In summary, these studies operationalized production swiftness as delivery speed, throughput time and cycle time.

2.1.2 Production evenness. The concept of variability reduction is a consistent theme in Lean production (Treville and Antonakis, 2006). Germain *et al.* (2008, p. 559) defined process variability within the supply chain as "level of inconsistency in the flow of goods throughout the firm". They identified the main sources of variability that hinder company's performance in a supply chain: supplier performance (i.e. variable delivery performance), variable throughput and inconsistent quality and changes in customer orders. From an operational perspective, the firm can control only the second source (variable throughput and inconsistent quality); the other two sources are external to the firm and can be managed through other organizational mechanisms such as supplier and customer relationship management. Empirical studies conceptualized variability reduction or production evenness using a variety of constructs (Table II).

Klassen and Menor (2007) explored the trade-offs between capacity utilization, variability and inventory (CVI) and distinguished between internal (i.e. process related) and

Table I. Production swiftness measures

Reference	Construct conceptualization	Findings
Koufteros *et al.* (1998)	Throughput time Cycle time	Quality improvement efforts coupled with pull production (setup redesign, cellular manufacturing and preventive maintenance) reduce the overall throughput time
Salvador *et al.* (2001)	Delivery speed Response time	Interactions with customers and suppliers, time-related practices, directly reduce the components that make up the delivery speed and response time
Powell and Schmenner (2002)	Throughput time	Higher output is achieved through lower throughput; quality defects, machine breakdowns and worker injuries negatively affect the output
Schmenner (2004)	Throughput time	Long throughput negatively affects the productivity; demand and process variability adversely affect the productivity
Kher and Fredendall (2004)	Flow cycle time	Reducing variance in job arrivals and processing times did significantly reduce flow times. Worker flexibility reduced flow time. Dispatching rules reduced processing times, by reducing the process variation
Seuring (2009)	Process optimization in supply chain	Product design in supply chains affects the supply chain strategy; process optimization in supply chain has positive impact on the success of the supply chain strategy
Fredendall *et al.* (2009)	Process flow target time	Process standardization affects the process flow; and it reduces quality problems and improves coordination of bottlenecks. Quality problems and bottleneck management practices negatively affect the process flow
Keil *et al.* (2011)	Production flow	Lean practices implementation lead to improvements in production flow and elimination of waste
van der Heijden *et al.* (2012)	Throughput time	Reduction of throughput time leads to improved product availability and reduction of inventory-associated costs
Devaraj *et al.* (2013)	Patient flow (length of stay)	Patient flow is a mediating variable, affected by IT, and can significantly affect the quality of patient care and financial performance

external (i.e. supply chain-related) variability. Internal variability refers to quality defects, equipment breakdown and worker absenteeism, and external variability refers to arrival of individual customers, transit time for local deliveries and quality of incoming supplies. Likewise, Kher and Fredendall (2004) suggested the main causes of variability as the manner in which orders arrive into the production floor and the amount of work that is associated with these orders. However, in general, there are few studies that have incorporated the explicit influence of variability into their performance analysis. These constructs are closely linked to process variability, more specific to quality variability/issues.

2.2 The impact of Lean practices on performance

The view that Lean practices yield superior operational performance has been widely researched (Panwar *et al.*, 2018; Knol *et al.*, 2018; Chugani *et al.*, 2017; Albliwi *et al.*, 2017). The literature on Lean practices is extensive, and numerous empirical studies, using large

Reference	Construct conceptualization	Findings
Germain *et al.* (2001)	Throughput variance (quality and flow)	Demand unpredictability is positively related to throughput variance, which in turn adversely affects the performance. Design knowledge minimizes throughput variance and positively affects the performance. Mass output orientation indirectly affects the financial performance, when mediated by throughout variance
Powell and Schmenner (2002)	Quality defects Machine breakdown Worker injury	Higher output is achieved through lower throughput; quality defects, machine breakdowns and worker injuries negatively affect the output
Kher and Fredendall (2004)	Worker flexibility Dispatching rules Variance in job arrivals and processing time	Reducing variance in job arrivals and processing times did significantly reduce flow times. Worker flexibility reduced flow time. Dispatching rules reduced processing times, by reducing the process variation
Schmenner (2004)	Process variability (quality) Demand variability (external)	Long throughput negatively affects the productivity; demand and process variability adversely affect the productivity
Klassen and Menor (2007)	Internal process variability (quality defects, equipment breakdown and worker absenteeism)	Reduction in internal process variability resulted in improvements in throughput time and inventory levels
Seuring (2009)	Product design in supply chain	Product design in supply chains affects the supply chain strategy; process optimization in supply chain has a positive impact on the success of the supply chain strategy
Fredendall *et al.* (2009)	Quality problems (interruptions operational failures, quality errors)	Process standardization affects the process flow; and it reduces quality problems and improves coordination of bottlenecks. Quality problems and bottleneck management practices negatively affect the process flow
Devaraj *et al.* (2013)	Patient care (quality of stay)	Patient flow is a mediating variable, affected by IT and can significantly affect the quality of patient care and financial performance

Table II.
Production evenness measures

cross-sectional data sets, investigated their effect on the operational performance (Bortolotti *et al.*, 2013). According to Inman *et al.* (2011), Lean practices focus on waste elimination through planning, scheduling and sequencing of operations. These practices eliminate waste, reduce throughput time and enhance the flow of goods along the transformation process (Tu *et al.*, 2001; Singh *et al.*, 2013; Habidin and Yusof, 2013). Lean manufacturing can be represented as a manufacturing system that incorporates a variety of practices such as JIT, repetitive production, process automation, setup time/throughput reduction, cellular manufacturing and pull production (Shah and Ward, 2003; Bayo-Moriones *et al.*, 2008; Furlan *et al.*, 2011; Narasimhan *et al.*, 2006). Numerous scholars have used similar frameworks to examine Lean manufacturing practices (Negrão *et al.*, 2017).

Das *et al.* (2007) presented in their research a model of cellular manufacturing system designs that minimized total system costs and maximized machine reliability. Similarly, Safaei *et al.* (2010) investigated the performance of the cellular manufacturing systems and found significant improvements in flow and efficiency of the manufacturing processes. Recent studies on setup time reduction (Benjamin *et al.*, 2013; Carrizo Moreira and Campos Silva Pais, 2011) have reported throughput time reduction, increased machine utilization and flexibility and decreased lot size. The reduction in setup time facilitates the implementation of pull production systems (Fahmi and Hollingworth, 2012). Muthiah *et al.* (2008) studied the effect of automation using overall equipment effectiveness measures and concluded that the use of data communication systems (software and hardware) provides management with a quantitative view of how good a factory is performing compared with its theoretically attainable level. The availability of such information helped managers to make informed productivity improvement decisions. Investments in factory automation have been reported as beneficial towards customer service and supply chain responsiveness (Kärkkäinen and Holmström, 2002).

Bayo-Moriones *et al.* (2008) examined the factors that determine the use of JIT in companies and the role of organizational context (size and age) and infrastructure practices (advanced manufacturing technologies, quality management and work organization). They found that infrastructural factors rather than contextual factors affect the operational performance and the use of the different components of JIT. Bortolotti *et al.*'s (2015b) study highlighted the positive association between Lean practices (such as daily schedule adherence, equipment layout, Kanban, setup time reduction and JIT delivery by suppliers) and operational performance. Therefore, we can posit that the level of adoption/implementation of Lean practices will have direct effects on production fitness:

H1a. The level of adoption/implementation of Lean practices affects production swiftness.

H1a′. The level of adoption/implementation of Lean practices affects production evenness.

2.3 The impact of quality practices on performance

The literature is abundant in studies on quality practices and their effect on operational performance (Dubey and Gunasekaran, 2015; Gambi *et al.,* 2015; Albliwi *et al.,* 2017; Parvadavardini *et al.,* 2016; Garza-Reyes *et al.,* 2015). The impact of individual or sets of quality practices and programmes, such as statistical process control, Six Sigma, TQM, internal supplier certification and external certifications (i.e. ISO 9000), has been vastly examined by researchers (Wiengarten *et al.,* 2013b; Kull and Wacker, 2010; Kim *et al.,* 2012; Sila, 2007).

Studies such as da Silveira and Sousa (2010) and Colledani and Tolio (2009) found significant impact of the use of statistical process control, particularly in management of production systems and improving responsiveness. It provided information feedback and allowed shop-floor personnel to take corrective action in a timely manner. The quality charts, graphs and tables were effective tools to raise quality awareness among employees and develop a culture focused on elimination of waste (Sadikoglu and Zehir, 2010; Yang *et al.,* 2011a).

Developing and managing supplier relationship has been identified as an important practice in quality management (Kull *et al.,* 2013; Fynes *et al.,* 2008). Globalization has provided companies with access to world-wide suppliers and further opportunities to increase the low-cost supply base (Chen and Yang, 2002) at the expense of other factors, particularly related to quality. This raises the importance of supplier management, and especially supplier integration and certification (Liker and Choi, 2004). According to Tan (2001), the ultimate goal of supplier certification is to improve quality at source, minimize communication errors and reduce inventory and duplication in inspection. Certification such ISO 9000 has been widely recognized as a quality management practice; however, the impact on firm performance is mixed, often contradictory (Starke *et al.,* 2012). Recent studies have cited benefits such as improved efficiency, process control, increased customer satisfaction, cost savings and perceived higher quality (Wiengarten *et al.*, 2017). Other researchers (Han and Chen, 2007; Kim *et al.*, 2011) have criticized the implementation of ISO as being expensive and time-consuming, with no tangible gains in performance. These contradictory views could be attributed to the use of macro measures of firm performance, such as market share, profit and customer base, which could be influenced by external factors, other than ISO certification. Several empirical studies reported positive Six Sigma benefits towards operational performance (Arumugam *et al.*, 2013; Linderman *et al.*, 2010; Albliwi *et al.*, 2017). Jones *et al.* (2010) proposed that the use of teams in Six Sigma implementations enhances the operational performance. This view is supported by Shafer and Moeller (2012), who stated that companies that adopt this practice are more efficient and stronger performers.

It is well established in the literature that quality approaches can be viewed as a strategic resource (O'Neill *et al.*, 2015; Parvadavardini *et al.*, 2016) that generates cultural value (Gambi *et al.*, 2015) and provides the company with superior operational performance (Dubey and Gunasekaran, 2015; Xiong *et al.*, 2016). Based on the discussion above, the following hypotheses could be stated:

H1b. The level of adoption/implementation of quality practices affects the production swiftness.

H1b′. The level of adoption/implementation of quality practices affects the production evenness.

2.4 Lean and quality practices–performance relationship

Several studies have investigated the internal and external fit of manufacturing practices with the environment (Donaldson, 2001; Sousa and Voss, 2008; Panwar *et al.*, 2018; Knol *et al.*, 2018; Garza-Reyes *et al.*, 2018). However, little research has been done on the fit and alignment between Lean and quality practices and their effect on operational performance (Negrão *et al.*, 2017; Chugani *et al.*, 2017). This study focuses on the internal fit between Lean and quality practices and takes a mediation perspective to investigate how their fit impacts on the production fitness. Therefore, if the indirect effects of the investments in Lean practices on production fitness are stronger than the direct effects of the investments in Lean practices on production fitness, then the investments in quality practices play a mediating role in the model.

Lean and quality practices have also been examined in terms of their fit and alignment (Wiengarten *et al.*, 2013b), and some researchers suggest that quality practices can be viewed as a catalyst for developing the operational strategy (Lau, 2000). For example, quality practices were found to form a strong foundation for the successful implementation of JIT practices (Prajogo and Brown, 2012; Fynes *et al.*, 2008). In this regard, Sousa and Voss (2008) found evidence that the TQM practices were contingent on manufacturing strategy and provided evidence that manufacturing practices when used in combination result in better manufacturing performance. More recent studies highlighted that Lean high performers tend to focus on quality practices (Narasimhan *et al.*, 2006), and their effect on Lean implementation contributed directly to overall manufacturing performance improvements (Danese *et al.*, 2017). Garza-Reyes *et al.* (2015) conducted the evaluation of Lean readiness of the Turkish automotive suppliers industry (T-ASI). Their results revealed that the T-ASI had a high level of Lean readiness, especially in the area of customer relations and top management and leadership.

In the literature, few studies posited the quality practices as a mediator. Most of the studies focus on the TQM as a quality program for supporting operational improvement. Hung *et al.* (2010) examined the relationship between knowledge management (KM), TQM and innovation performance. They found that KM initiatives have an indirect effect on innovation performance via the mediator TQM. Likewise, Demirbag *et al.* (2006) examined the impact of market orientation and implementation of quality management practices on organizational performance of small medium enterprises (SMEs). Their findings indicate that SMEs may not realize increased performance gain with a successful market orientation, but when quality management is implemented alongside market orientation, better financial performance can be achieved. More recently, Prajogo and Brown (2012) examined the TQM practices mediation role on the relationship between the organization strategy and operational performance. Their findings indicate that TQM is positively and significantly related to differentiation strategy, and it only partially mediated the relationship between differentiation strategy and organization's performance. Their findings support the argument that quality management implementation needs to be complemented by other resources to more effectively realize the strategy in achieving superior performance.

From the discussion above, we posit that the level of investments in quality practices mediates the impact of the level of investments in Lean practices and influences the magnitude of their impact on production fitness. Thus, we advance the following hypotheses:

H2a. The level of investments in quality practices mediates the relationship between the level of investments in Lean practices and production swiftness.

H2b. The level of investments in quality practices mediates the relationship between the level of investments in Lean practices and production evenness.

Based on the literature review and the hypotheses developed, the research framework is shown in Figure 1. The framework proposes that investments in quality practices mediate the impact of investments in Lean practices on operational performance, conceptualized as production fitness (swiftness and evenness, respectively). A detailed description of the production fitness was presented in the above subsections, and then the impact of Lean/quality practices on production fitness was discussed (direct effects), followed by the

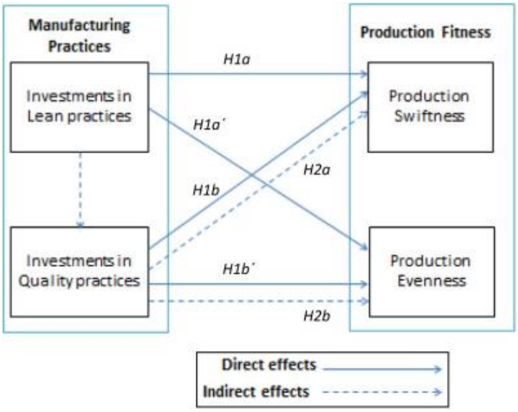

Figure 1.
Theoretical framework with hypotheses

mediation between quality and Lean practices and their impact on production fitness (indirect effects).

3. Research methodology

Data were collected as part of the GMRG, a multinational group of OM researchers who focus on the study and improvement of manufacturing companies worldwide. Details regarding the questionnaire development and data collection process can be found in the work by Whybark *et al.* (2009). Standardized survey instruments were developed over a number of years and administered by GMRG members in their respective country. The questionnaire is made of modules on supply chain management, sustainability, planning and control, innovation and culture. All modules have been designed based on specific literature and to explore manufacturing practices and performance taking place at the plant level. The data used in this paper are part of the fourth round and over 1,400 responses were collected, representing 23 countries in most regions of the world, which adds to the generalizability of the results (Prester, 2012). The manufacturing plant was the unit of analysis and the plant managers were the key respondents. The benefits of using this data set are the data come from a multinational study, the sample size is large enough to carry out rigorous analysis of the data and the unit of analysis is the manufacturing plant, which increases the contextual validity of the results (J. Power, 2014). Following a rigorous approach of only considering records for which we had no missing data for all our variables of interest led us to a data set containing 844 records (Table III).

3.1 Measures

Lean and quality practices were measured by considering the plant's level of practice investments in the previous two years (Appendix). Respondents were asked to indicate on a scale from 1 to 7 the level of resources (money, time and/or people) invested in these practices. Also, respondents were asked to indicate the level of production fitness improvement using an index of 100 as a starting point two years ago (e.g. a 5 per cent increase would be 105 or 5 per cent decrease would be 95). The production swiftness assessed the improvements in flow speed made by the plant in terms of manufacturing throughput time, cycle time and delivery speed (Zhang and Sharifi, 2007; Schoenherr and Narasimhan, 2012; White *et al.*, 2010). The production evenness assessed the improvements in variation associated with the process in terms of rejects of incoming material, rejects during processing, rejects at final inspection and customer returns (Kroes and Ghosh, 2010; Wiengarten *et al.*, 2013b).

Number of employees	*n*	Industry	*n*	Country	*n*	Country	*n*
Less than 50	208	Automotive	35	Australia	40	Italy	38
51-100	194	Chemical	39	Austria	11	Macedonia	20
101-500	315	Electrical/ Electronic	157	China	52	Mexico	67
501-1,000	62	Food	81	Croatia	62	Poland	48
Over 1,000	65	Metal/Plastic Fabrication	295	Fiji	107	Sweden	23
		Utility	74	Finland	121	Swiss	21
		Textile goods	54	Germany	47	Taiwan	47
		Other	109	Hungary	46	USA	63
Total	844			Ireland	31		

Table III.
Sample overview

3.2 Factor analysis: validity and reliability

Confirmatory factor analysis (CFA) was conducted using AMOS to assess the validity and reliability characteristics of the measures. The results are presented in Table IV in terms of factor loadings, *t*-values, standard errors and R^2s. Using Hu and Bentler's (1998) goodness-of-fit values, the comparison indicated that the model is satisfactory (root mean square error of approximation = 0.026, goodness of fit index = 0.98, adjusted goodness of fit index = 0.97, normed fit index = 0.97, comparative fit index = 0.98, incremental fit index = 0.98, relative fit index = 0.96). The ratio of chi-square to degrees of freedom was 1.61, which is below the threshold of 3 (MacCallum and Austin, 2000).

Content and face validity were examined through the involvement of numerous OM scholars and researchers involved at the development stage of the survey. All the items used are well grounded in the OM literature. Convergent validity is the extent to which indicators of a specific construct "converge" or share a high proportion of variance in common. To assess convergent validity, we examined construct loadings and standard error. The results indicated that each coefficient was greater than twice its associated standard error (Anderson and Gerbing, 1988). Discriminant validity measures the extent to which a construct is truly distinct from other constructs. Discriminant validity was confirmed through inter-factor correlations, which were in an acceptable range. The reliability (internal consistency) was tested, and all constructs had a minimum of 0.728, indicating reliable measures. Before proceeding with the analysis of the results, we conducted common method bias tests. The variance that is linked to the measurement method rather than to its constructs was evaluated by re-running the CFA with an additional unmeasured factor. The constructs continued to load on their initial assigned latent variables; therefore, it was concluded that common method variance was not of significance in this data set (Podsakoff *et al.*, 2003).

Table IV.
Measurement characteristics

Construct/variable	Loading	*t*-value	SE	R^2
Investments in Lean practices ($\alpha = 0.737$)				
Manufacturing throughput time reduction	0.66	16.38	0.062	0.44
Process redesign	0.49	11.23	0.071	0.24
Cellular manufacturing	0.49	12.74	0.071	0.24
Setup time reduction	0.76	20.16	0.066	0.58
Factory automation	0.53	14.14	0.065	0.28
Investments in quality practices ($\alpha = 0.809$)				
Six Sigma	0.58	21.61	0.073	0.34
ISO 9000	0.57	16.35	0.078	0.32
Supplier certification	0.75	21.11	0.070	0.56
Statistical process control	0.77	21.52	0.069	0.59
Production swiftness improvements ($\alpha = 0.808$)				
Cycle time	0.76	23.49	0.598	0.58
Manufacturing throughput time	0.91	31.10	0.593	0.77
Delivery speed	0.59	17.78	0.693	0.53
Production evenness improvement ($\alpha = 0.728$)				
Rejects of incoming material	0.66	15.56	0.217	0.44
Rejects during processing (scrap rate)	0.65	11.01	0.307	0.42
Rejects at final inspection	0.54	11.60	0.248	0.29
Returns from customers	0.52	12.79	0.208	0.27

4. Results

The null hypotheses regarding the direct effect of the Lean practices on production fitness were tested. Table V presents the results of the SEM in testing these hypotheses.

Based on the results, *H1a* did not receive support; therefore, higher levels of investments in Lean practices did not have a significant impact on the improvements related to production swiftness. In contrast, *H1a′* received support, and higher levels of investments in Lean practices were associated with improvement in production evenness. The result is significant, with $p < 0.01$. This means that 1-point increase in the level of investments in Lean practices leads to 0.17 increase in the improvement of the production evenness.

The null hypotheses regarding the direct effect of the quality practices on production fitness were tested (*H1b* and *H1b′*). Table VI presents the results of the SEM in testing these hypotheses.

Based on the results of the SEM, both hypotheses were supported. The results were significant, with $p < 0.05$ for *H1b* and $p < 0.01$ for *H1b′*. In practical terms, this means that a 1-point increase in the levels of investments in quality practices leads to 0.12 increases in production swiftness and 0.17 increases in production evenness.

The null hypotheses regarding the mediating indirect effect of the Lean practices on production fitness were tested (*H2a* and *H2b*). To test for mediation, Rungtusanatham *et al.*'s (2014) procedural recommendations were followed. They suggest the estimation of three regression equations: first, regress the mediator on the independent variable (IV); second, regress the dependent variable (DV) on the IV; and third, regress the DV on the mediator and the IV. These three equations will provide the tests of the linkages of the mediational model. AMOS software was used to test the mediation effects, using the bootstrapping technique to calculate the separate indirect effects via the mediating factor. According to Baron and Kenny (1986), the following conditions must be met to establish mediation: the IV must affect the mediator, the IV must be shown to affect the DV and the mediator must affect the DV. If these conditions hold, then the size of the direct effect with mediation must be less than the size of the direct effect without the mediator. When the IV has no direct effect with mediation, it is known as full mediation. In this study, the mediation model contains Lean practices (IV), quality practices (mediator), production swiftness (DV for *H2a*) and production evenness (DV for *H2b*).

The indirect effect is calculated by multiplying the two direct path coefficients, which are the direct effect of Lean on quality and the direct effects of quality practices on production

Hypotheses	Path	Path coefficient	Hypothesis supported?
H1a	Lean practices → Production swiftness	NS	No
H1a′	Lean practices → Production evenness	0.17**	Yes

Note: $^{**}p < 0.01$; NS – nonsignificant

Table V.
Path analysis: lean practices and production fitness

Hypotheses	Path	Path coefficient	Hypothesis supported?
H1b	Quality practices → Production swiftness	0.12*	Yes
H1b′	Quality practices → Production evenness	0.17**	Yes

Note: $^{*}p < 0.05$; $^{**}p < 0.01$

Table VI.
Path analysis: quality practices and production fitness

fitness, swiftness and evenness, respectively (Kline, 2005). Following the outlined methodology, the results are presented in Table VII.

Rungtusanatham *et al.* (2014) suggest that following Baron and Kenny's (1986) approach requires also the Sobel's test to check the significance of the indirect path. This is a specialized t test that determines whether the reduction in the effect of the IV, after including the mediator in the model, is a significant reduction, and that the mediation effect is statistically significant (Fairchild and McQuillin, 2010). For each hypothesis, tests were performed for the corresponding paths.

H2a. Sobel's t-values = 2.408; SE = 0.473; p value = 0.01

H2b. Sobel's t-values = 2.715; SE = 0.117; p value < 0.01

The table above and Sobel's test results indicated support for both hypotheses. Lean practices showed a significant indirect effect on production fitness through quality practices. This showed that companies investing in Lean practices improve their production fitness if investments in quality practices are present.

5. Discussion

Our study was set out to explore two research questions:

RQ1. To what extent the Lean and quality practices impact the factory fitness?

RQ2. To what extent the quality practices mediate the relationship between Lean practices and factory fitness?

This study is anchored on the work of Schmenner (2012) and Ferdows and Thurnheer (2011) in terms of its operationalization of the factory fitness concept using the theory of SEF constructs. In addition, it provides insights into the relationships between Lean and quality practices and their effect on the factory fitness.

The contribution of this research is twofold: first, in providing a comprehensive investigation of the impact of Lean and quality practices on factory fitness; and second, in assessing whether the quality practices enhance the efficacy of Lean practices. Using a global data set, the study makes multiple theoretical and practical contributions.

5.1 Theoretical implications

The literature review has outlined the need for further research on how the efficacy of Lean practices can be increased, to enhance the factory fitness (Panwar *et al.*, 2018; Nadeem *et al.*, 2017; Danese *et al.*, 2017). Although previous studies investigated the Lean and quality practices effects on operational performance, there is little research on the mediational effects. Our study contributes to advancing the OM knowledge, by testing the internal fit between Lean and quality practices taking a mediation perspective.

Table VII. Path analysis: indirect effects

Hypotheses	Path	Direct effect without the mediator	Direct effect with mediation	Indirect effect
H3a	Lean → Quality → PS	0.144**	NS	0.08*
H3b	Lean → Quality → PE	0.272**	0.166**	0.11*

Note: $^{*}p < 0.05$; $^{**}p < 0.01$.

The empirical results revealed that Lean practices positively affect the production evenness (*H1a′*). This is consistent with previous studies supporting that adoption of concurrent Lean practices reduces the production variability associated with a process (Fahmi and Hollingworth, 2012; Singh *et al.*, 2013). However, we did not find any evidence that investments in Lean practices support the improvements in production swiftness (*H1a*), in terms of improvement of cycle time, throughput time or delivery time. Although this research does not confirm previous studies on the positive effects of Lean practices on time-related measures (Ahmad *et al.*, 2003; Fullerton and Wempe, 2009), it rather is consistent with those studies that are more restrained about this positive influence (White *et al.*, 2010; Danese *et al.*, 2012). A possible interpretation of this finding is that Lean practices do not directly impact the production swiftness, as this is also influenced by quality practices.

We found support for the hypothesis that investments in quality practices positively impact the production swiftness and evenness (*H1b* and *H1b′*). These findings are in line with other studies (Fynes and Voss, 2001; Prajogo and Sohal, 2006; Honarpour and Asadi, 2012; Yunis *et al.*, 2013; Parvadavardini *et al.*, 2016) and highlight the importance of implementing quality practices that enable manufacturing organizations to improve their production swiftness and evenness.

This is the first study to operationalize and empirically test the factory fitness concept proposed by Ferdows and Thurnheer (2011). The development of the factory fitness was based on using the theory of SEF as a theoretical lens. Factory fitness was conceptualized as production swiftness and evenness. Swiftness was defined as the speed of the production flow, and evenness represented the variability associated with that process. The model of building production fitness is an extension of the sand cone model proposed by Ferdows and De Meyer (1990), and the results showed that building production evenness leads to improvement in production swiftness. In other words, factories can improve their fitness cumulatively. This empirical study answers the call for more research to test the factory fitness model and confirms that improvements in the factory fitness are contingent upon certain conditions.

A major contribution of this study is the mediating role of quality practices in the relationship between Lean practices and production fitness (*H2a* and *H2b*). In addition to the primary effects of these practices, several studies have evidenced their tendency to reinforce each other (Singh *et al.*, 2013; Longoni *et al.*, 2013; Chavez *et al.*, 2013; Fahmi and Hollingworth, 2012; Aronsson *et al.*, 2011) and that their combination yields superior performance improvements. Quality practices were found to form a strong foundation for the successful implementation of Lean practices (Fynes *et al.*, 2008; Prajogo and Brown, 2012; Yunis *et al.*, 2013). Our findings revealed that the direct effect of Lean practices decreased in magnitude in the presence of the quality practices, thus suggesting that quality practices partially mediated the link between the Lean practices and production evenness. The relationship between Lean practices and production swiftness was not significant in the presence of quality practices, which asserted that quality practices fully mediated their link. It supports the findings of *H1a*, where Lean practices did not affect directly the production swiftness. This is a significant contribution to theory in that it explains not only how the Lean practices affect the production swiftness but also the role of quality practices in facilitating the improvement in production fitness.

This study is important to the development and testing of theory, as it integrates two research streams, Lean practices and SEF, to gain insights into the building of production fitness. Our findings contribute to theory by examining the interplay between Lean and quality practices and how the mediation effect influences the production swiftness and evenness. Empirical research in operations management research can benefit from examining for additional mediation effects, to better understand the mechanisms through which the manufacturing practices yield superior performance (Bortolotti *et al.*, 2013; Danese *et al.*, 2012; Brown and Vondráček, 2013; Nair *et al.*, 2013).

5.2 Practical implications

Schmenner *et al.* (2009) suggested that research in operations management has failed to be integrative and that there is "too much theory not enough understanding". It is important to link the development of theory to practice and provide support for advancing the knowledge. From a practical perspective for operations managers, we provide insights on the way better-performing plants compete. Our findings offer operations managers a better understanding of production fitness and how Lean practices affect its development. This study helps managers make better decisions with regard to investments in Lean practices and recognize different operational consequences. To gain production swiftness, companies must focus on reducing the process variability, thus improving their evenness. When viewed through the SEF theory lens, the findings of this study provide managers with empirical evidence that investments in Lean and quality practices can lead to improvements in production fitness.

Our review of the literature highlighted the lack of studies that examine the fit between Lean (Bortolotti *et al.*, 2015a; Danese *et al.*, 2012) and quality practices (Parvadavardini *et al.*, 2016; Garza-Reyes *et al.*, 2015). This research has confirmed the importance of alignment and fit as an enabler for competitive positioning. When developing the manufacturing strategy, managers must closely look at their competitive priorities and decide on the manufacturing practices that need to be implemented. The alignment and fit between Lean and quality practices is paramount in achieving superior production fitness. The findings revealed that Lean practices affected the production swiftness indirectly, through the implementation of quality practices. This is an important finding, as it explains how managers can reap the benefits of Lean practices and offers an understanding of the mechanisms that can be used to achieve better results. The results highlight that the implementation of Lean practices yields better results on production evenness, when the company has higher levels of investments in quality practices. As such, the implementation of quality practices is a prerequisite for achieving higher production fitness. This finding is in line with the cumulative or sand cone theory and suggests that from a practical point of view, companies should focus first in realizing high levels of production evenness (reduce variability) to support the development of other capabilities such as production swiftness.

6. Conclusions

In this paper, we revisited and extended the theory of SEF with its investigation of the impact of Lean and quality practices on the improvement of factory fitness. As such, we responded to prior calls for research that supported further research of this domain (Schmenner, 2012; Devaraj *et al.*, 2013). Specifically, this study revisited the theory by its investigation in the GMRG data set. The unit of analysis for this study was the manufacturing site or plant, which is the most appropriate level to study operations management strategy (Schoenherr and Narasimhan, 2012). In addition, this study extended the theory of SEF by the development of the measures for swiftness and evenness. Furthermore, we confirm the mediating role of quality practices in the relationship between Lean practices and factory fitness. This is a significant contribution in that it explains not only how the Lean practices affect the production swiftness but also the role of quality practices in facilitating the improvement in factory fitness.

Although this study makes significant theoretical and practical contributions, the limitations need to be noted. First, this study investigates the implementation and performance impact of Lean and quality practices at the company level. Future research could try to extend this study and measure its implications at the supply chain level. Second, this research has used perceptual measures for its constructs. The variables in study were latent and measurable only through indicators (Boyer and Swink, 2008). It has been suggested that the perceptual measures can raise potential measurement errors stemming from subjectivity and bias (Malhotra and Grover, 1998). In this study, the measurement quality was assessed; however, the argument of measurement error and the alternative of objective measures are acknowledged.

Third, the development of the swiftness and evenness measures can be further refined. Although the constructs in this study have been developed to be theoretically sound, further related elements can be encapsulated to gain a better understanding of the phenomena. More objective measures would contribute to the advancement of factory fitness indicators. The literature has highlighted the lack of empirical studies that have conceptualized the theory of SEF and further research is required.

Fourth and final, the use of longitudinal research could provide valuable contributions to theory development and refinement in the fields on OM. The research methodology used in this study is cross-sectional; therefore, it does not examine the causal patterns of manufacturing practices over a period. It is recommended that a longitudinal design can provide a more rich and detailed explanation of the process of building factory fitness throughout different implementation stages of Lean and quality practices.

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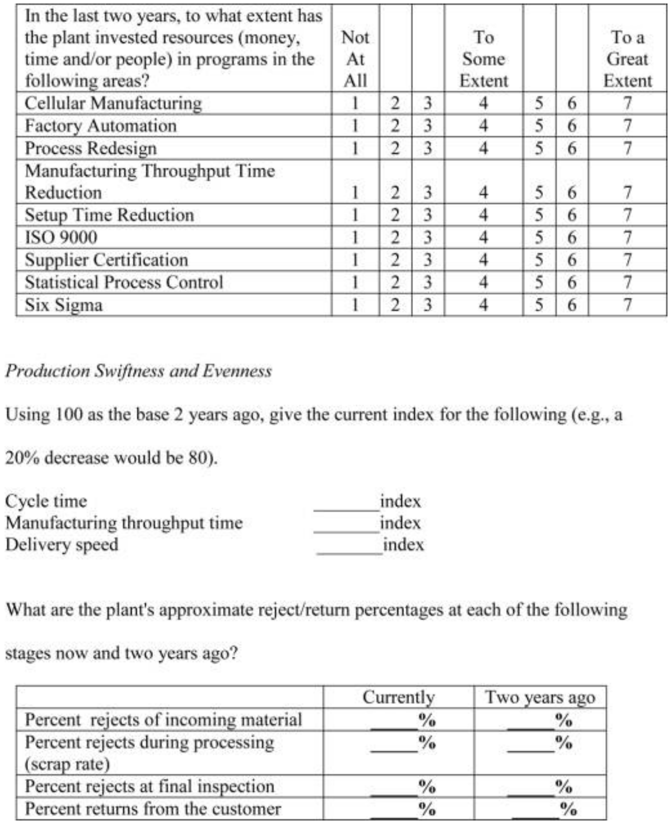
Appendix

Survey Instrument

Investments in manufacturing practices



In the last two years, to what extent has the plant invested resources (money, time and/or people) in programs in the following areas?	Not At All			To Some Extent			To a Great Extent
Cellular Manufacturing	1	2	3	4	5	6	7
Factory Automation	1	2	3	4	5	6	7
Process Redesign	1	2	3	4	5	6	7
Manufacturing Throughput Time Reduction	1	2	3	4	5	6	7
Setup Time Reduction	1	2	3	4	5	6	7
ISO 9000	1	2	3	4	5	6	7
Supplier Certification	1	2	3	4	5	6	7
Statistical Process Control	1	2	3	4	5	6	7
Six Sigma	1	2	3	4	5	6	7

Production Swiftness and Evenness

Using 100 as the base 2 years ago, give the current index for the following (e.g., a 20% decrease would be 80).

Cycle time ________index
Manufacturing throughput time ________index
Delivery speed ________index

What are the plant's approximate reject/return percentages at each of the following stages now and two years ago?

	Currently	Two years ago
Percent rejects of incoming material	_____%	_____%
Percent rejects during processing (scrap rate)	_____%	_____%
Percent rejects at final inspection	_____%	_____%
Percent returns from the customer	_____%	_____%

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